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Brief Report

The role of inferior vena cava diameter in volume status monitoring; the best sonographic measurement method?☆

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ABSTRACT

Objectives: This study aims to determine the site of and the best sonographic method for measurement of inferior vena cava (IVC) diameter in volume status monitoring.

Methods: This observational before-and-after study was performed at the intensive care unit of the emergency department. It included hypotensive adult patients with suspected sepsis who were recommended to receive at least 20 mg/kg fluid replacement by the emergency physician. The patients were fluid replaced at a rate of 1000 mL/h, and maximum and minimum IVC diameters were measured and the Caval index calculated sonographically via both B-mode and M-mode. Hence, IVC's volume response was assessed by a total of 6 parameters, 3 each in M-mode and B-mode. Freidman test was used to assess the change in IVC diameter with fluid replacement. Wilcoxon test with Bonferroni correction was used to determine which measurement method more sensitively measured IVC diameter change.

Results: Twenty-eight patients with a mean age of 71.3 were included in the final analysis.The IVC diameter change was significant with all 6 methods ($P < .001$). The IVC minimum diameter change measured on M-mode during inspiration (M-mode i) was the only measurement method that significantly showed diameter change with each 500-mL fluid replacements. The initial and the subsequent M-mode i values after each 500 mL of fluid were 5.65 ± 3.34; 8.05 ± 3.66; 10.16 ± 3.61, and 11.21 ± 2.94, respectively ($P < .001$, $P < .002$, and $P < .003$, respectively).

Conclusion: Inferior vena cava diameter was changed by fluid administration. The M-mode i method that most sensitively measures that change may be the most successful method in volume status monitoring.

1. Introduction

Assessing and monitoring intravascular volume status are critical parts of the management of critically ill patients. Currently, the volume status is assessed by physical examination, vital sign assessment, measurement of biochemical markers, tissue perfusion, and central venous pressure (CVP), and sonographic assessment of inferior vena cava (IVC) diameter [1]. Physical examination, one of the simplest and most rapid methods among them, is not reliable for assessment of intravascular volume status [2,3]. Blood pressure, on the other hand, may remain relatively normal until 30% of total body water is lost, which is sufficient for multiple-organ dysfunction [4]. Therefore, various advanced methods including CVP monitorization, pulmonary artery catheterization, esophageal catheterization, transesophageal echocardiography, and transthoracic echocardiography (TTE) are sometimes needed. Unfortunately, most of these methods require special knowledge and skills, and they cause significant time loss for the patients in the emergency department. Moreover, there is no consensus for the indications of the traditional invasive monitorization methods [5,6]. All these invasive methods are a source of potential morbidity and mortality. Noninvasive methods have thus recently become more popular [7]. Among them, IVC diameter ultrasound measurement (IVC-USG) has been reported to reliably reflect volume status [8–14], although there have also been studies suggesting otherwise [15–17]. Most important of all, CVP is considered as gold standard when the relationship between the IVC diameter and intravascular volume is studied [18–21]. However, the accuracy of CVP measurement in reflecting volume status is controversial [22–24]. A total of 803 patient meta-analyses containing 24 studies demonstrated that there is only a weak correlation between CVP and volume status [23]. This has caused the value of CVP to be debated.

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Studies on the relationship between IVC diameter and volume status in volunteer blood donors without taking CVP into account have yielded varying results [8,16]. These data suggest that there is an ongoing need for studies that examine the relationship between IVC and volume status.

The first objective of the present study was to determine whether there was a relationship between sonographically measured IVC diameter and intravascular volume status. The second objective was to find out which of the IVC measurement methods was most successful in reflecting the accurate volume status.

2. Methods

2.1. Study design and setting

We designed a prospective, observational, single-center study with a before-and-after design to determine the relationship between fluid replacement and IVC diameter. The study design dictated repeated measurements of IVC diameter after each 500-mL saline replacement. This study was conducted after it was approved by the education planning committee of the hospital. Each study subject gave a written informed consent.

The study was conducted in the emergency department of a training and research hospital in Turkey. The emergency department in question annually serves 200 000 patients, of whom 5% to 10% are treated at the intensive care unit located in the emergency department. All emergency medicine residents working at our hospital are certified by the emergency medicine societies for basic and advanced ultrasonography after attending basic and advanced ultrasonography courses. This study was conducted between December 1, 2012, and March 15, 2013.

The study included patients more than 18 years of age who presented to our emergency department with hypotension (systolic blood pressure [SBP] < 100 mm Hg or mean arterial pressure (MAP) < 65 mm Hg] and clinically suspected sepsis (Fig. 1) and were recommended to receive fluid replacement at an amount of 20 ml/kg or greater by the emergency physicians. Pregnancy, active trauma, cardiopulmonary arrest, intubation, severe tricuspid regurgitation (TR), or incalculable fluid losses (diarrhea, vomiting, and acute abdomen) were the reasons for exclusion from the study.

2.2. Study protocol

The IVC-USG measurement was performed by an emergency medicine resident having 2 years of experience in ultrasonography. That resident received a 6-hour theoretical training followed by practice training on 20 patients.

The first measurement was made within 10 minutes of emergency department admission, once the initial physical examination was completed. The measurements were performed with a SonoScape (S6/S6 Pro) branded portable ultrasonography device, using a 3.5- to 5-mHz convex transducer. The IVC-USG measurements were performed from the subxiphoid region with the patient being in the supine position. The measurements were made while the patient remained in the relaxed position, and the respiratory movements of the patients were not directed by the performer. As a first step of measurement, aorta and IVC were located transversely and their positions were confirmed by Doppler interrogation. Then, the view was shifted to the longitudinal line over IVC; the right atrial entry of IVC was spotted, and 2 cm distal to this point the IVC diameter was measured via a commonly utilized method recommended by the American College of Emergency Physicians (ACEP) and the measurement line perpendicular to both IVC walls [25–27]. A video recording was done during at least 3 respiratory cycles, first in B-mode and then in M-mode. The video recording was paused at the maximum diameter in expiration in B-mode (B-mode e), and a measurement was done (Fig. 2A). During the same respiratory cycle, the recording was again paused at the minimum diameter in inspiration in B-mode (B-mode i), and a repeat measurement was done (Fig. 2B). The same measurements were made from the M-mode video recordings as well (M-mod e in expirium and M-mod i in inspirium; Fig. 2C). The IVC collapsibility index was calculated with the formula (IVCe − IVCi)/IVCe × 100 and recorded.

Once the initial measurement was done, fluid infusion at a rate of 1000 mL/h was commenced, and it was stopped after 500 mL of fluid was infused. After waiting for 1 cardiac cycle, the same measurements as above were done for the second time. The measurements were repeated for a third and fourth time after 1000 and 1500 mL of fluid were administered, respectively. Pulse rate and blood pressure were also measured and recorded simultaneously with the IVC measurements.

All patients underwent a full transthoracic echocardiographic examination (TTE) by a consulting cardiologist within 24 hours of admission. The IVC-USG measurements, TTE measurements, and clinical and laboratory data obtained were recorded in Microsoft Office Excel 2007 software.

2.3. Primary data analysis

In complementary analyses, frequency numbers were used to present the continuous variables, and the frequency tables (marginal tables)

Terms	Definitions
Systemic Inflammatory Response Syndrome (SIRS)	Response is manifested by 2 or more of the following condition: ➢ Fever of more than 38°C (100.4°F) or less than 36°C (96.8°F) ➢ Heart rate of more than 90 beats per minute ➢ Respiratory rate of more than 20 breaths per minute or arterial carbon dioxide tension ($PaCO_2$) of less than 32mmHg ➢ Abnormal white blood cell count (>12,000/µL or < 4,000/µL or >10% immature [band] forms
Sepsis	The presence of at least two of the above SIRS criteria in addition to clinical and microbiological evidence of infection
Severe Sepsis	Sepsis associated with organ dysfunction, hypoperfusıon(lactic acidosis,oliguria, acute alternation in mental status) or hypotension.
Septic shock	Sepsis-induced hypotension despite adequate fluid resuscitation along with presence of perfusion abnormalities.

Fig. 1. Definitions of the terms Systemic Inflammatory Response Syndrome and sepsis.